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USAAVLABS TECHNICAL REPORT 69-52

BALLISTIC TEST AND EVALUATION OF FORMED SECTIONS OF HEAT-TREATABLE DUAL-PROPERTY STEEL ARMOR (U)

By

Earl C. Gilbert

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June 1969

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June 1969

BALLISTIC TEST AND EVALUATION OF FORMED SECTIONS OF HEAT-TREATABLE DUAL-PROPERTY STEEL ARMOR (U)

Final Report

By

Earl C. Gilbert

Downgraded at 3 Year Intervals Declassified After 12 Years DOD DIR 5200.10	SPECIAL HANDLING REQUIRED NOT RELEASABLE TO FOREIGN NATIONALS

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(U) SUMMARY

This report contains the results of ballistic testing of fabricated sections of Dual-Property Steel Armor (DPSA). Specific items considered were bent, rolled, and extruded sections that simulated the geometry of close-fitting armor for critical aircraft components. Ballistic data for flat-plate sections were available prior to this program; however, the data did not include the geometric or fabrication effects. The purpose of this program was to determine whether the ballistics armor characteristics changed as a result of fabrication. Within the range of the formed sections tested, no significant changes were noted in the ballistic properties of the material as a result of the forming operations.

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(U) INTRODUCTION

In the past, Dual-Property Steel Armor (DPSA) has been primarily installed, when used in Army aircraft, in flat-plate configurations. This resulted in an inefficient use of armor material on a weight basis. Material can be used more efficiently if it can be formed to the shape of the components being protected.

DPSA is a roll-bonded steel composite. The hard front surface (Rockwell C-60) shatters the projectile on impact, while the more ductile rear element (Rockwell C-50) provides the toughness necessary to prevent the armor from shattering.

Whittaker Corporation, Nuclear Metals Division, has developed the processing and manufacturing techniques for forming DPSA shields for critical aircraft components. This work was done under Contract DAAJ02-68-C-0021 with U. S. Army Aviation Materiel Laboratories (USAAVLABS). Under this contract, Whittaker Corporation also formed several test specimens which were in turn tested in USAAVLABS' Dynamics Laboratory. This report describes the results of these tests. The techniques used to fabricate the test specimens are described in USAAVLABS Technical Report 69-15.*

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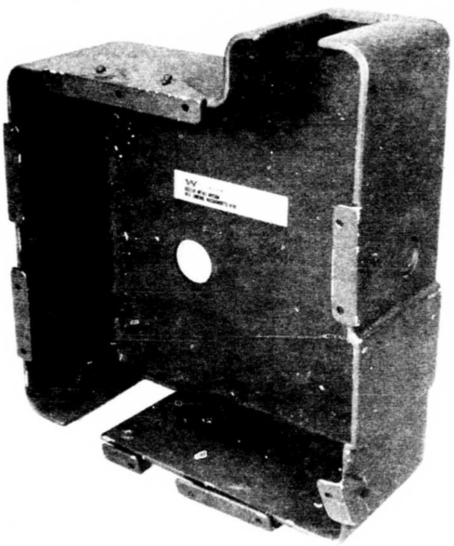
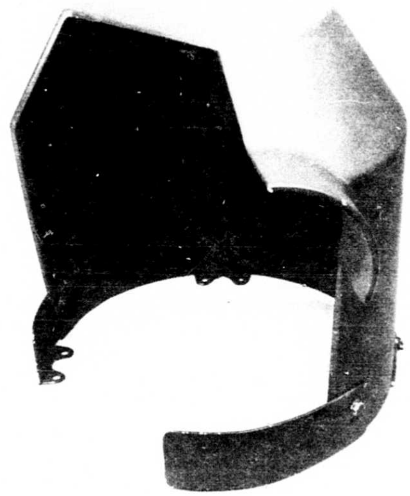
*Joseph L. Sliney, MANUFACTURING TECHNOLOGY - DUAL PROPERTY STEEL ARMOR FOR AIRCRAFT COMPONENTS, Whittaker Corporation; USAAVLABS Technical Report 69-15, U. S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, April 1969.

(U) TEST MATERIAL

Under the contract, Whittaker Corporation fabricated several component shields for the CH-47A helicopter (see Figure 1). As another part of the program, Whittaker formed the test specimens shown in Figures 2, 3, and 4. These specimens included bent flat-plate sections with various bend radii, rolled sections with large roll radii, and extruded DPSA tubing. The flat-plate thickness of the specimens prior to forming was approximately 9/32 inch. These flat-plate sections were cut and formed in the annealed condition and then heat treated to obtain a Rockwell C-60 hardness on the front surface and a Rockwell C-50 hardness on the rear surface. The cylinders were fabricated using a coextrusion process and were also heat treated to obtain the Rockwell C-60 and C-50 hardness values on the outer and inner surface respectively.

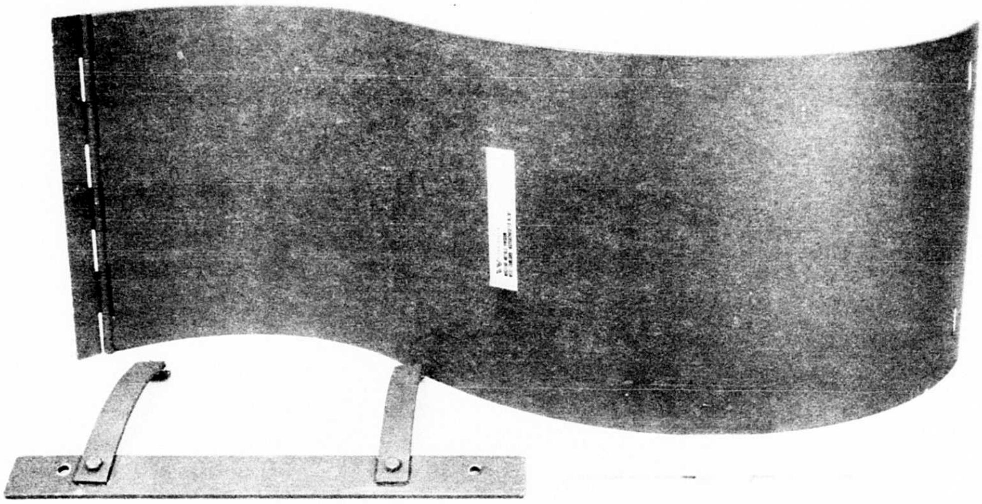


(a) Forward Transmission Sump Shield

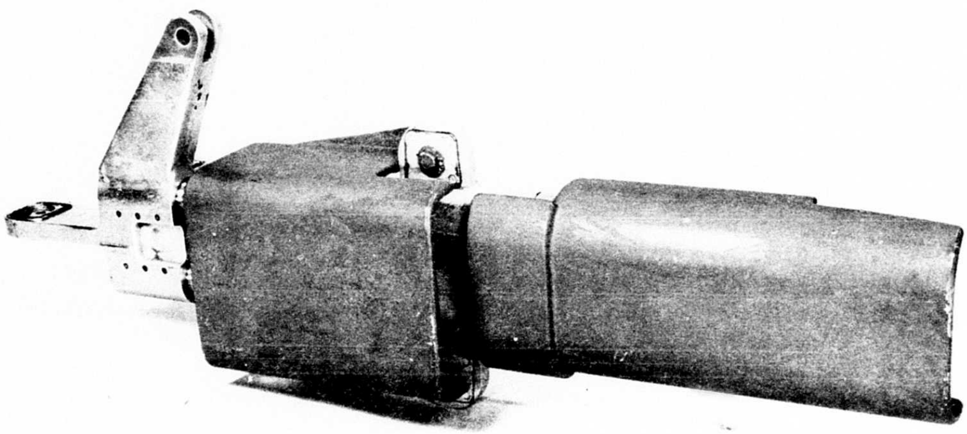


(b) High-Speed Transmission Shield

Figure 1. Experimental DPSA Shields for Critical CH-47A Helicopter Components.



(c) Engine Compressor Shield



(d) Actuator Shield

Figure 1. Continued.

Figure 2. Bent Sections.

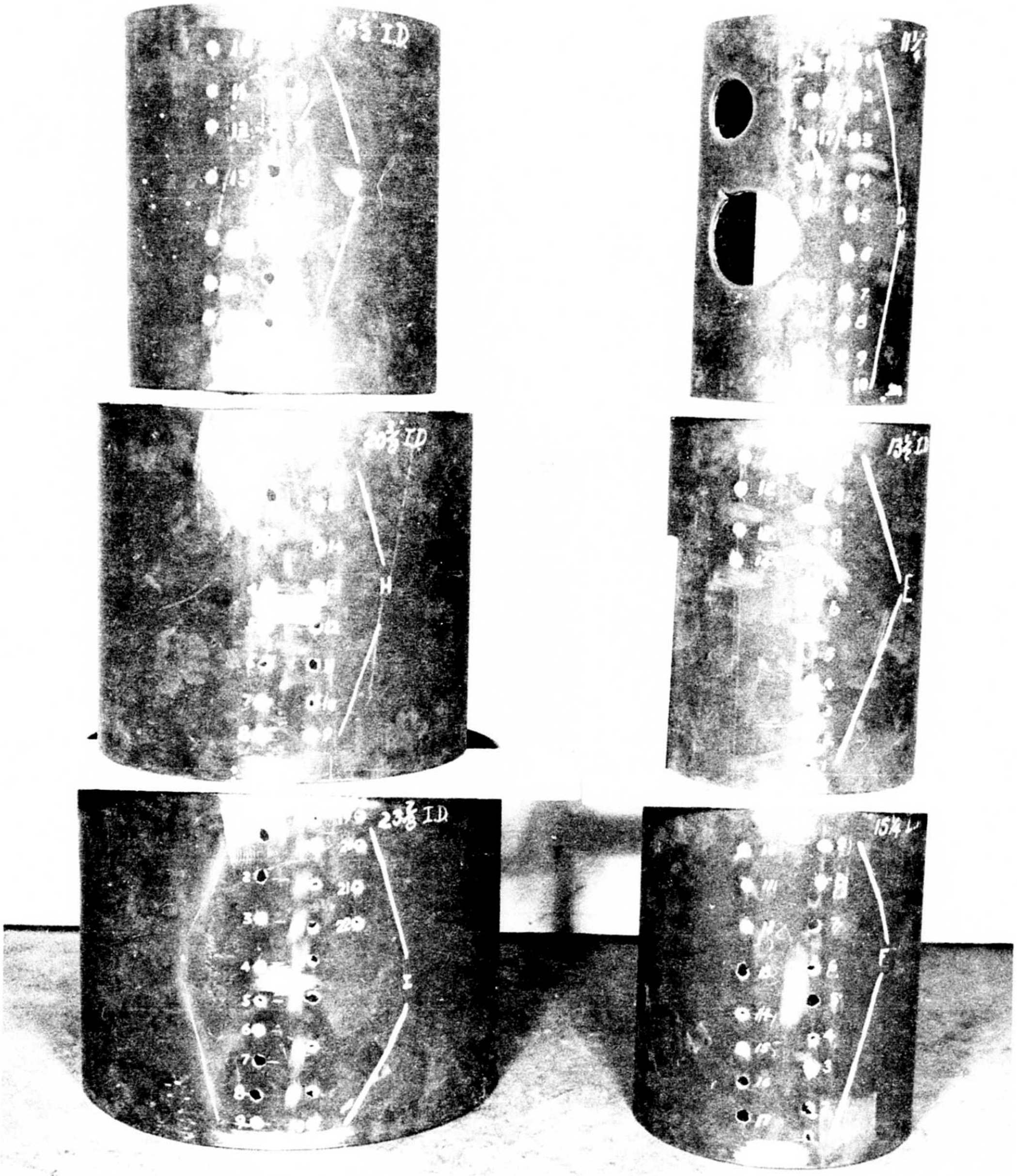


Figure 3. Rolled Sections.

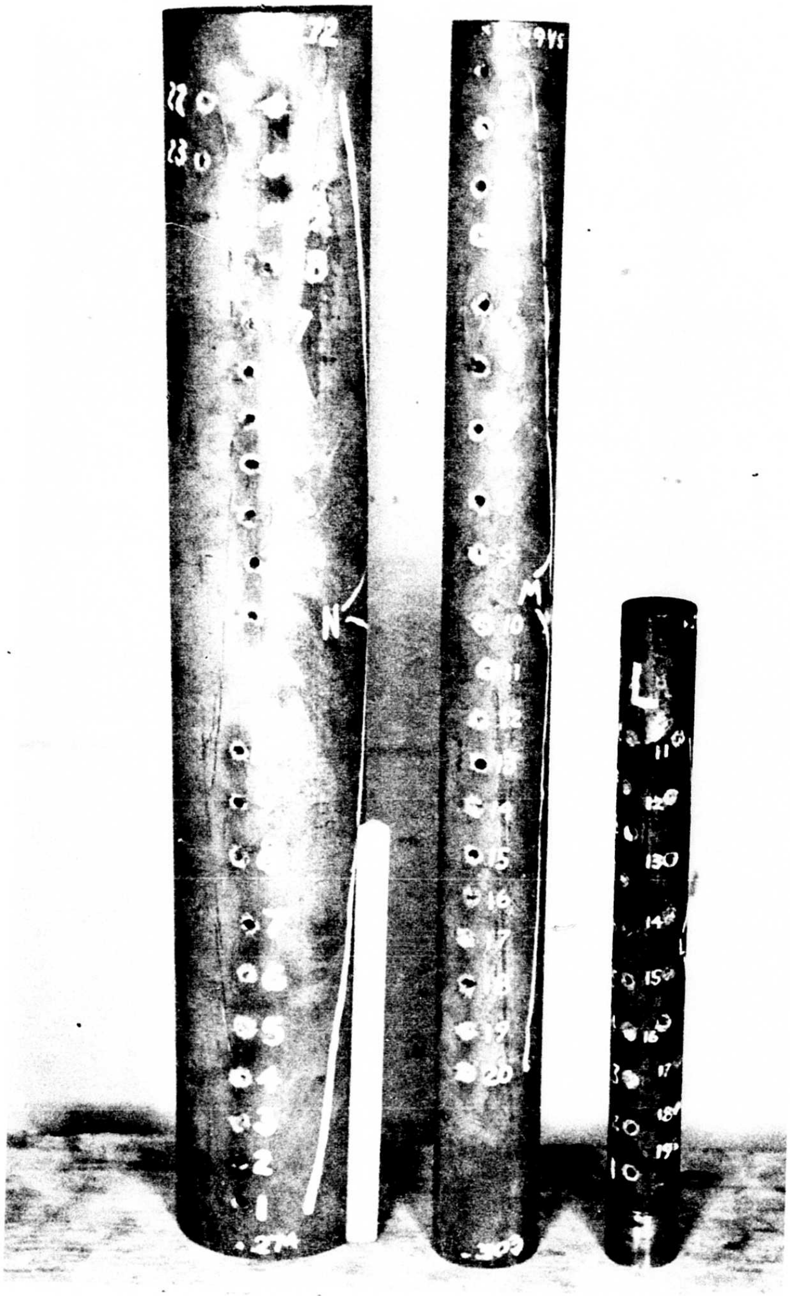


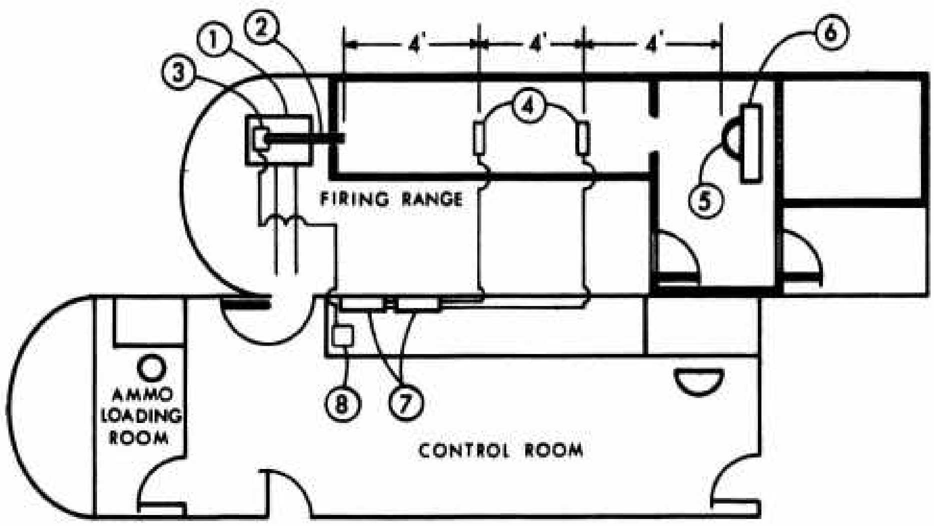
Figure 4. Extruded Sections.

(U) TEST FACILITY AND EQUIPMENT

The test program was conducted in the USAAVLABS Dynamics Laboratory, which consists of a ballistic range and a control room. A schematic of the Dynamics Laboratory is shown in Figure 5. Test firings were made from a Springfield Rifle, Model 1903A3 (caliber .30), held in a Frankford Arsenal holding fixture. The test specimens were mounted in a locally manufactured positioning fixture.

A Transistor Specialities, Incorporated, Model No. 361 Chronograph was used to measure the projectile velocity. This instrument was calibrated just prior to and following the test program.

Standard military caliber .30 AP M2 ammunition was reloaded in a commercially available reloading set to obtain the desired projectile velocities.



(1) UNIVERSAL FIXTURE
(2) CALIBER .30 RIFLE
(3) FIRING SOLENOID
(4) CHRONOGRAPH SCREENS
(5) TEST MATERIAL
(6) HOLDING FIXTURE
(7) CHRONOGRAPHS
(8) FIRING SWITCH

Figure 5. Schematic of Test Setup and Dynamics Laboratory.

(U) TEST PROCEDURES

Upon receipt of each test specimen, the surface hardness, both front and rear, was determined. The test specimens were then placed in the holding fixture and ballistically impacted with caliber .30 AP M2 projectiles. Projectile velocity was varied by reloading the ammunition with a measured quantity of powder.

Prior to firing, the rifle was boresighted such that the projectile impacted normal to the surface radius. The test specimens were repositioned after each shot, and the powder charges were altered to vary the projectile velocities close to the ballistic limit. A number of shots were made on each test specimen, and the highest velocities for three partial penetrations were averaged with the three lowest velocities from complete penetrations to obtain the ballistic limit (V_{50}) for the specimen. Maximum allowable spread permitted between the selected velocities was 150 feet per second. Actual velocities were measured with the chronograph.

(C) TEST RESULTS (U)

(U) The test results are summarized in the table on page 10. The actual ballistic limits (V_{50}^{A}) referred to in the table were calculated from the test data. The required ballistic limits (V_{50}^{S}) are based on the requirements of MIL-S-46099.* The results of tests A, B, B^1, B^{11}, and C are included in this table; however, they were not used in arriving at any of the conclusions because either the data were inadequate (because of the limited number of firings) or the hardness of the specimen did not meet the requirements of MIL-S-46099. With the exception of the 13-1/2-inch-diameter rolled section (specimen E), all the specimens tested had ballistic limits that were less than those required by the specification.

(U) Figure 6 shows the ballistic limit obtained from the tests plotted as a function of the formed radius of the specimen. This plot shows no correlation between the ballistic limit and the forming radius. Also, comparison of the ballistic limit of the tested flat specimens A^1 and C^1 with that of the formed sections did not reveal any significant difference. The scatter in the plotted data points appeared to be completely random for the specimens formed from plate and was probably a function of other variables such as small differences in hardness and thickness of the material, projectile yaw angle, and projectile hardness. The ballistic limit for the extruded specimens was slightly less than that for the other sections and appears to be a function of the manufacturing process rather than the specimen's radius. All test specimens showed excellent multi-hit capability, especially when impacted below the ballistic limit. Only small areas, approximately equal to the cross-sectional area of the projectiles, were affected.

(U) Many impacts that completely penetrated the flat plates and the rolled and bent sections produced large back spall plugs, as shown in Figure 7. These plugs were often found imbedded 1/2 inch to 3/8 inch in the fir boards that were located 12 inches to the rear of the tested specimens. Review of the data sheets shown in the appendix and the photographs of the tested specimens shown in Figures 8 through 32 indicates that the higher the impact velocity above the ballistic limit, the greater the probability that back spall plugs would form. No back spall plugs were formed when the extruded sections were penetrated; however, their ballistic limit was slightly less than that of the other sections (see Figure 6).

*Military Specification MIL-S-46099, STEEL ARMOR PLATE, ROLL-BONDED, DUAL HARDNESS, 15 November 1966.

TABLE. (C) SUMMARY OF TEST RESULTS (U)

TEST SPECIMEN	TYPE OF SECTION	THICKNESS (In.)	HARDNESS (Rc)		BALLISTIC LIMIT		$V_{50}^A - V_{50}^S$ (ft/sec)
			Front	Rear	Actual (V_{50}^A) (ft/sec)	Required (V_{50}^S) (ft/sec)	
A	3/8" Radius, Bent	.288	62	52	-	2638	-
A^1	Flat Plate	.288	62	52	2636	2638	-2
B	1/2" Radius, Bent	.287	60	51	-	2632	-
B^{11}	5/8" Radius, Bent	.287	57	48	2416	2632	-216
B^1	Flat Plate	.287	57	48	2515	2632	-117
C	7/8" Radius, Bent	.288	59	51	-	2638	-
C^1	Flat Plate	.288	59	51	2628	2638	-10
D	5-5/8" Radius, Rolled	.288	60	51	2511	2638	-127
E	6-3/4" Radius, Rolled	.285	60	52	2648	2620	+28
F	7-5/8" Radius, Rolled	.287	61	53	2621	2632	-11
G	8-1/4" Radius, Rolled	.284	60	51	2591	2614	-23
H	10-3/16" Radius, Rolled	.287	60	51	2630	2632	-2
I	11-15/16" Radius, Rolled	.287	60	53	2575	2632	-57
L	3/4" Radius, Extruded Tube	.288	59	-	2545	2638	-93
M	2-1/4" Radius, Extruded Tube	.299	59	-	2505	2695	-190
N	2-3/4" Radius, Extruded Tube	.293	59	-	2503	2665	-162

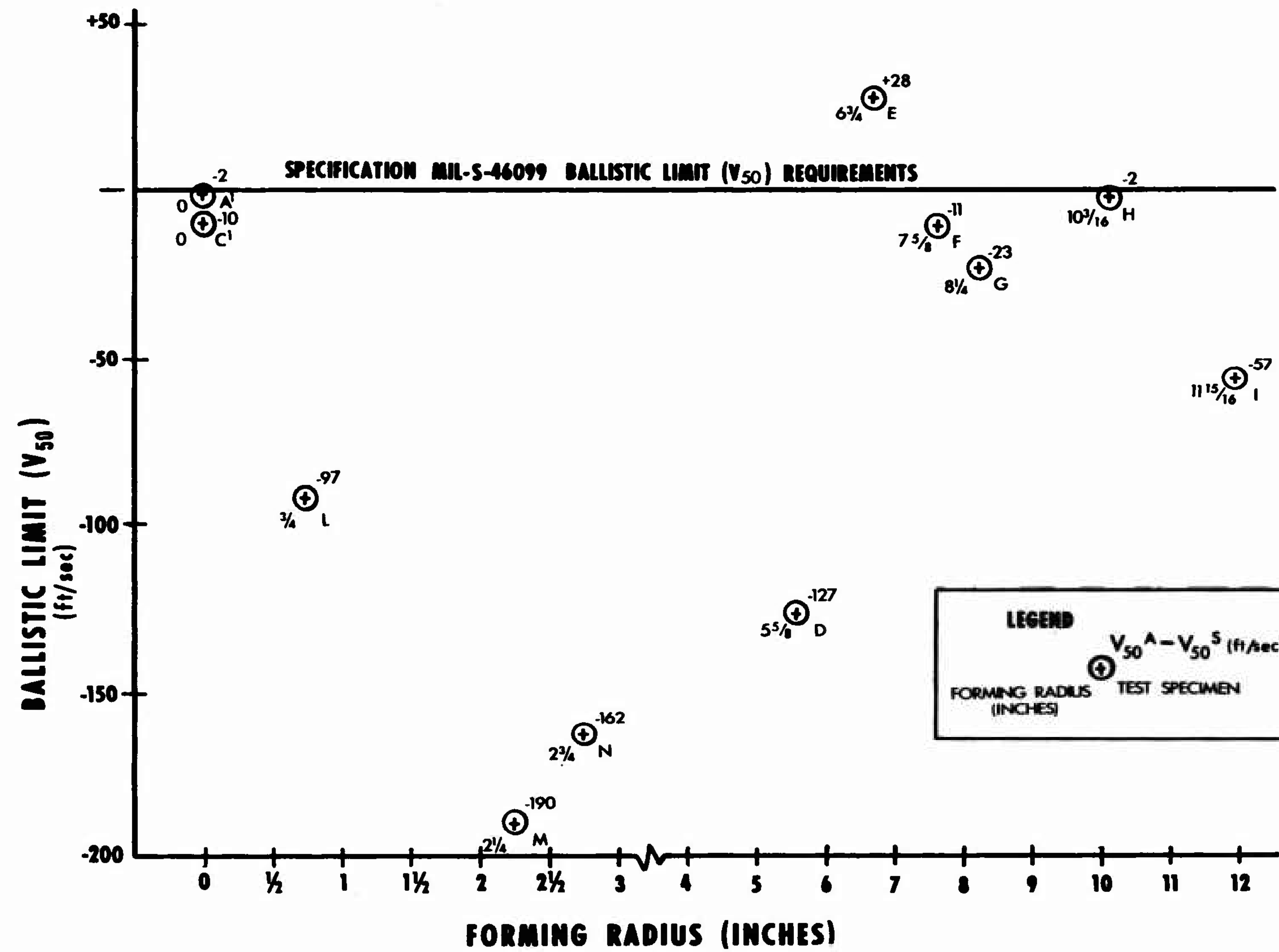


Figure 6. (U) Ballistic Limit (V_{50}) Versus Forming Radius.

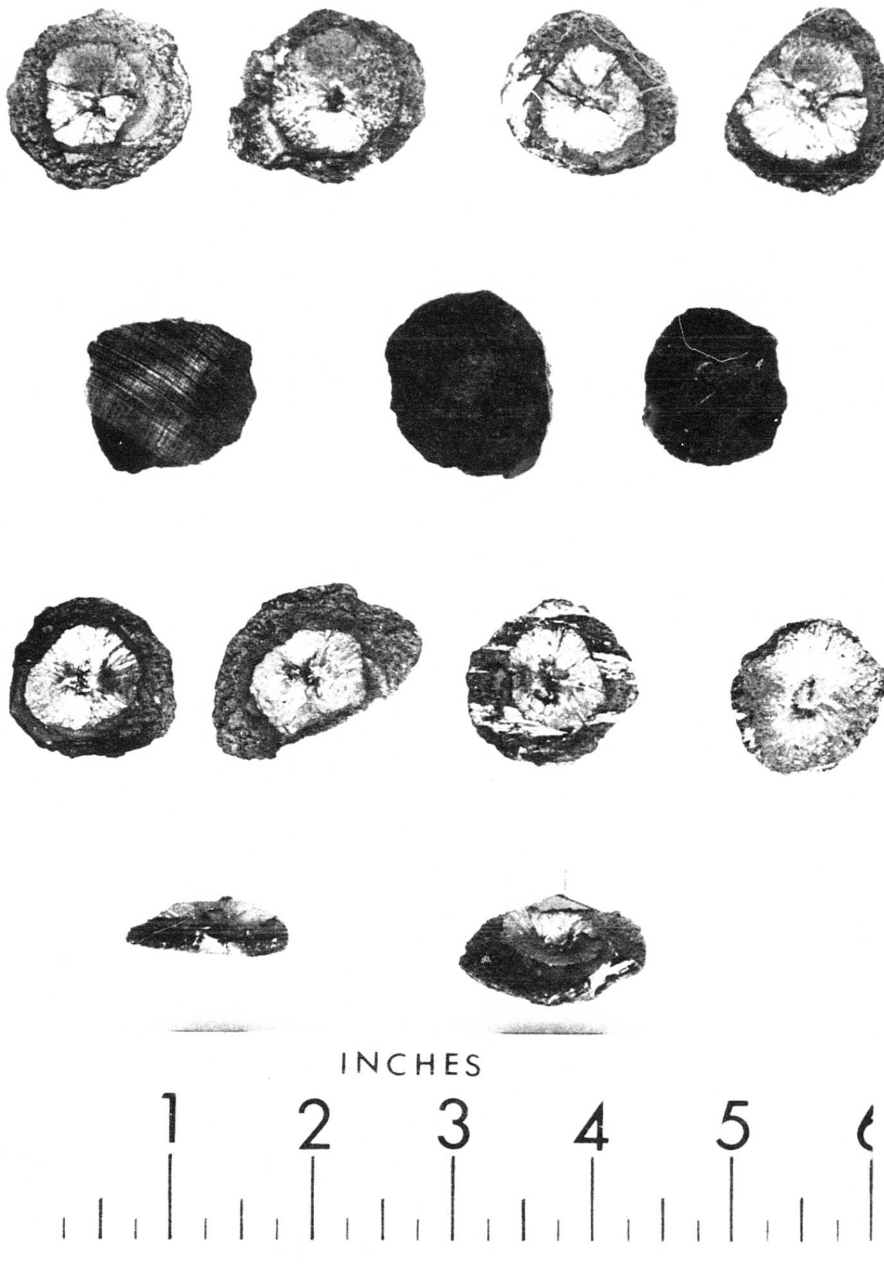


Figure 7. (U) Typical Back Spall Plugs.

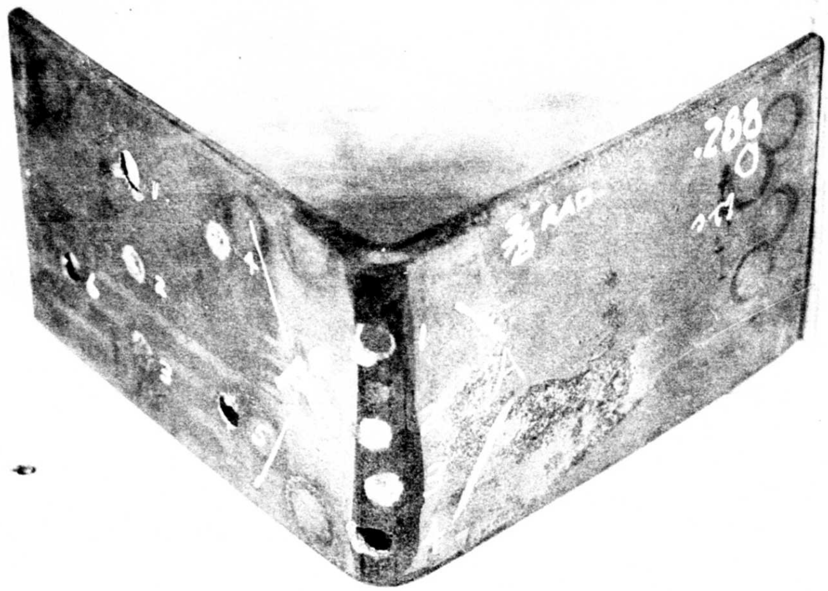


Figure 8. (U) Front, Test Specimens A and A^1.

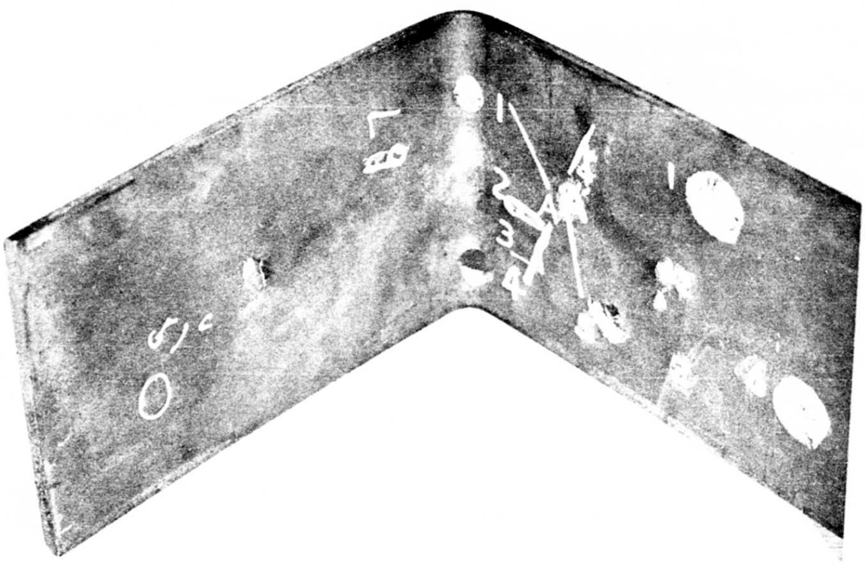


Figure 9. (U) Rear, Test Specimens A and A^1.

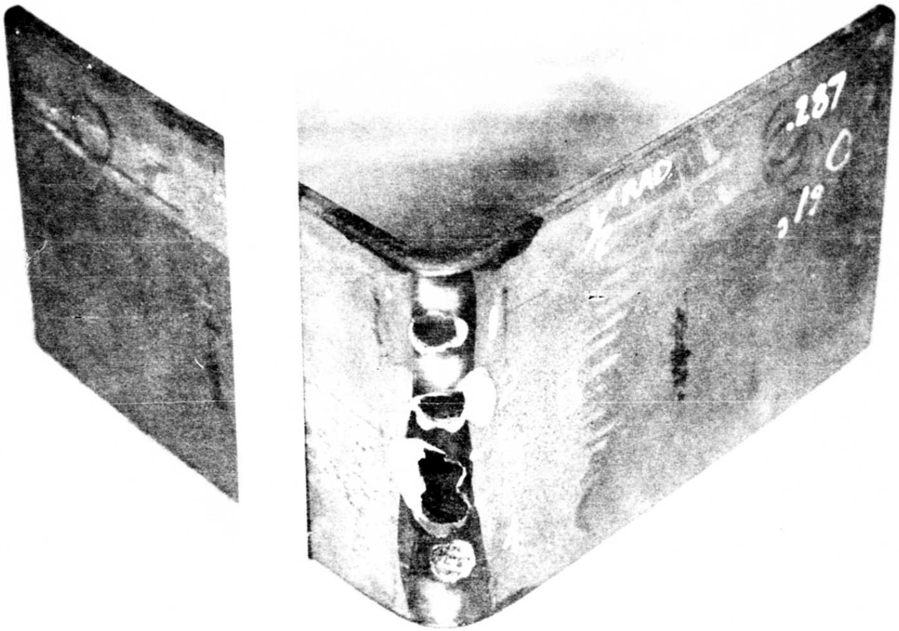


Figure 10. (U) Front, Test Specimen B.

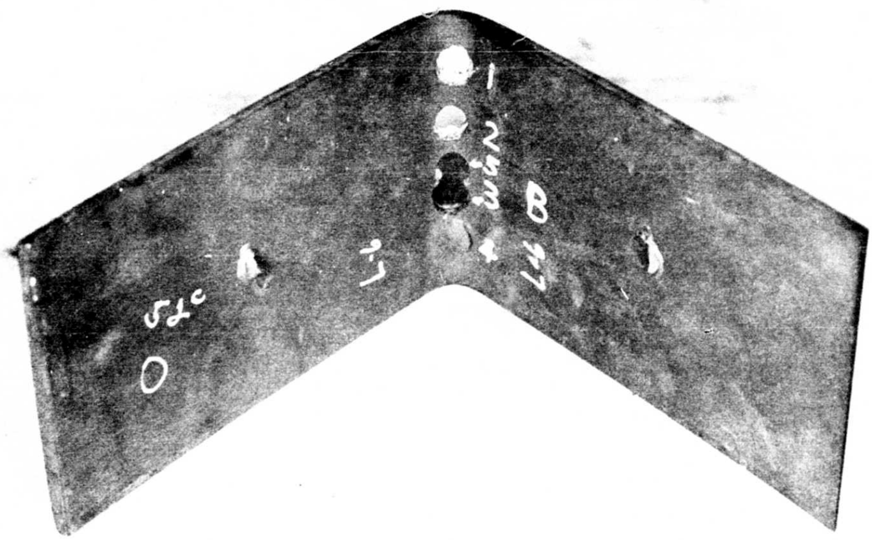


Figure 11. (U) Rear, Test Specimen B.

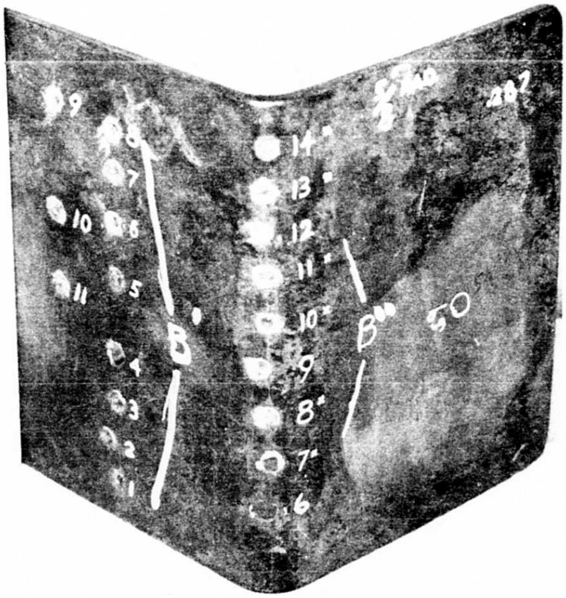


Figure 12. (U) Front, Test Specimens B^1 and B^{11}.

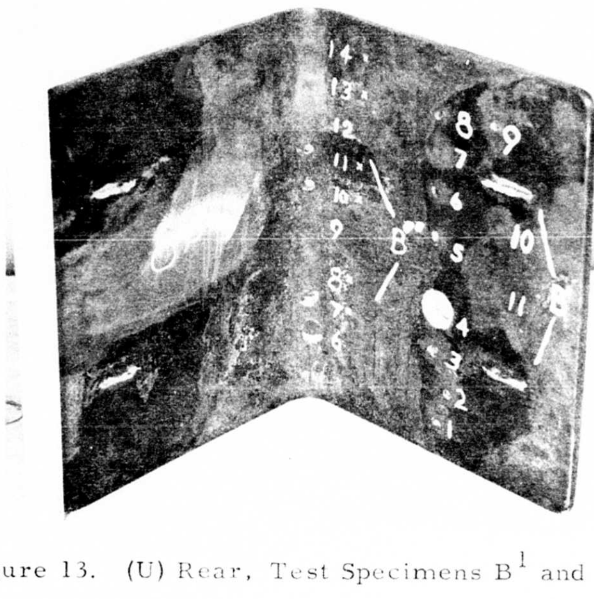


Figure 13. (U) Rear, Test Specimens B^1 and B^{11}.

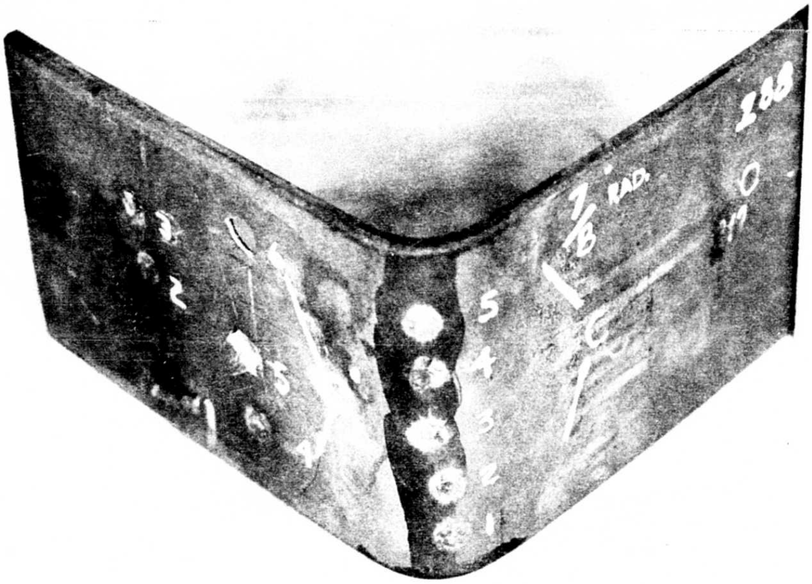


Figure 14. (U) Front, Test Specimens C and C^1.

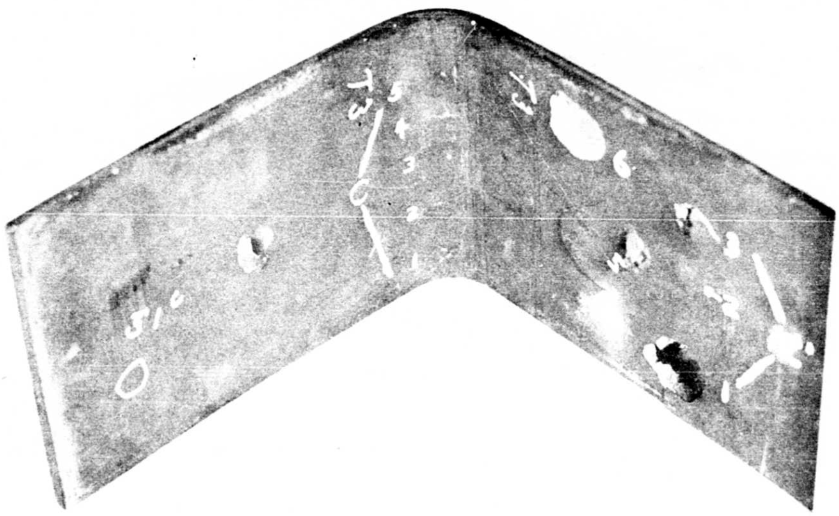


Figure 15. (U) Rear, Test Specimens C and C^1.

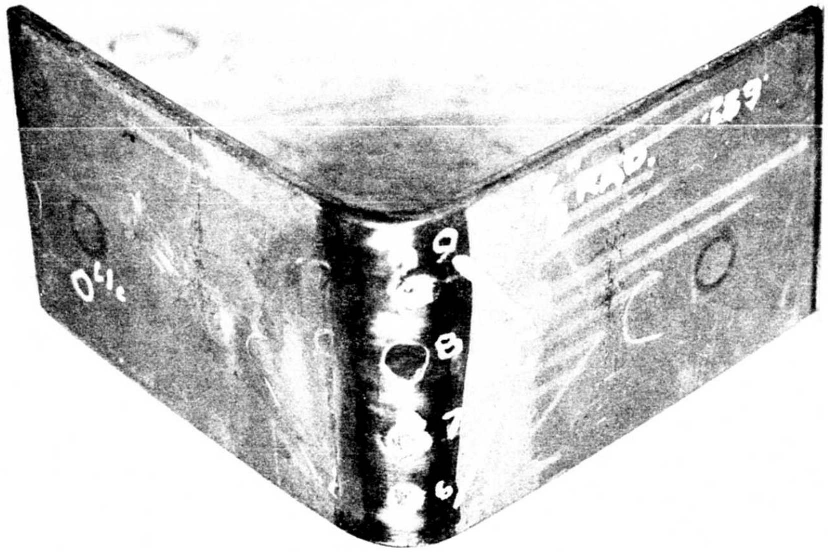


Figure 16. (U) Front, Test Specimen C.

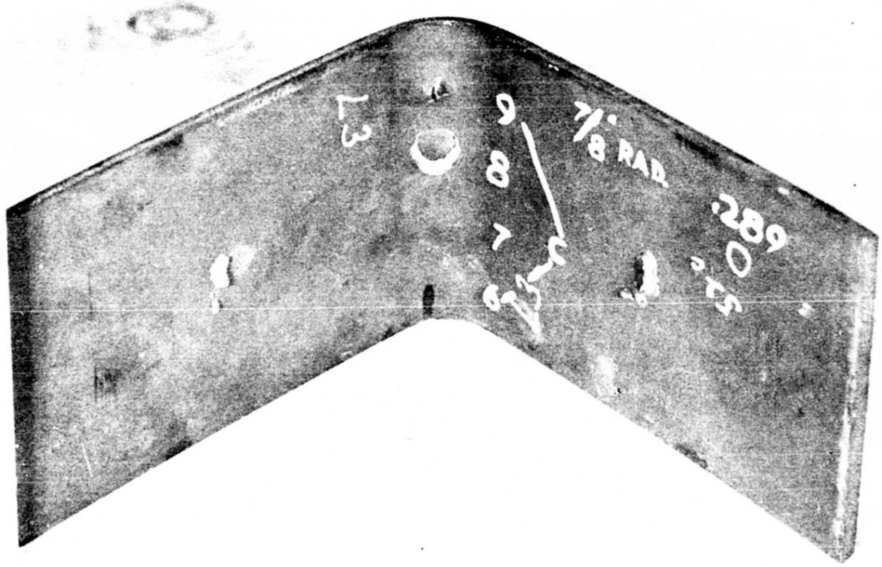


Figure 17. (U) Rear, Test Specimen C.

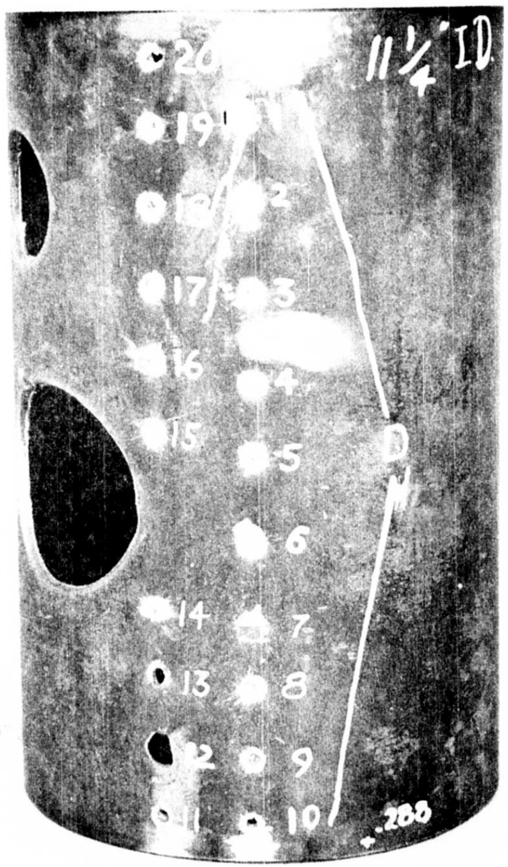


Figure 18. (U) Front, Test Specimen D.

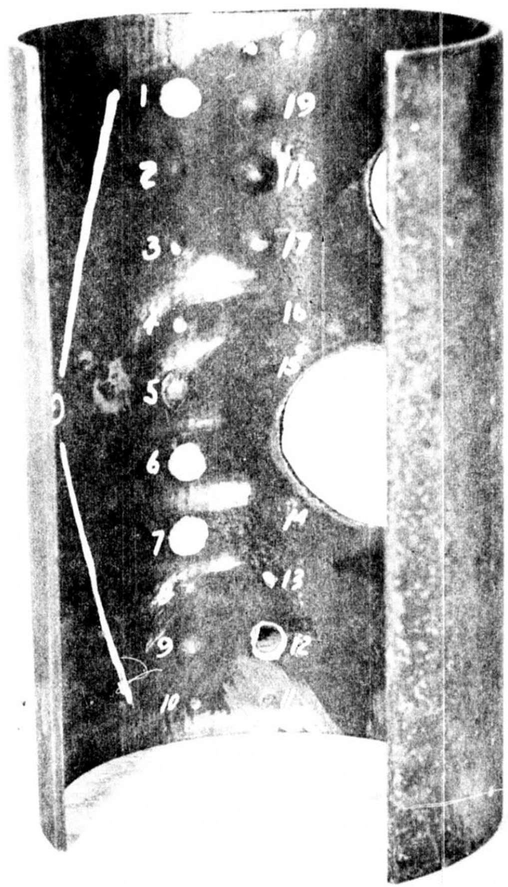


Figure 19. (U) Rear, Test Specimen D.

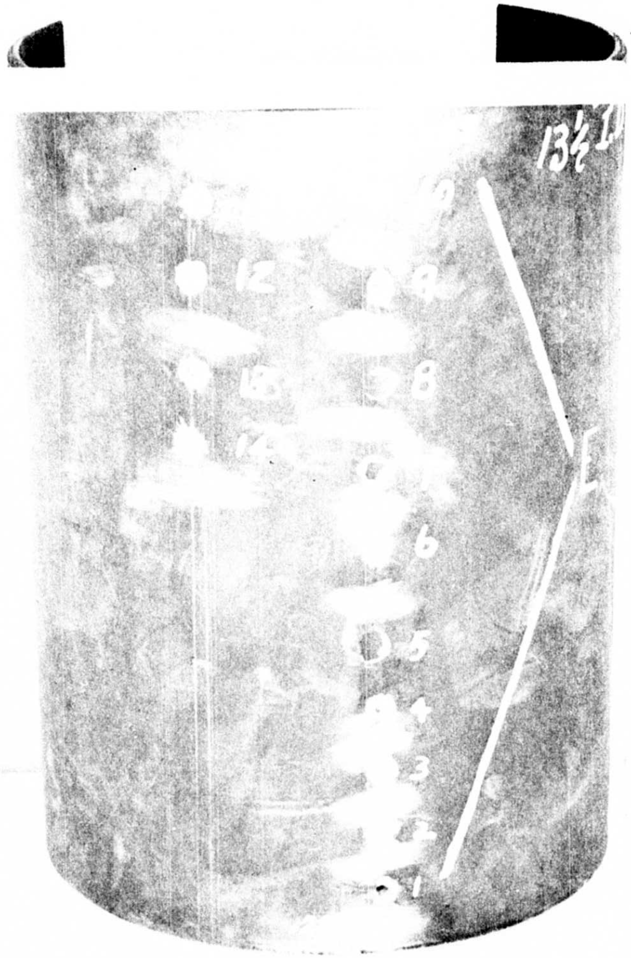


Figure 20. (U) Front, Test Specimen E.

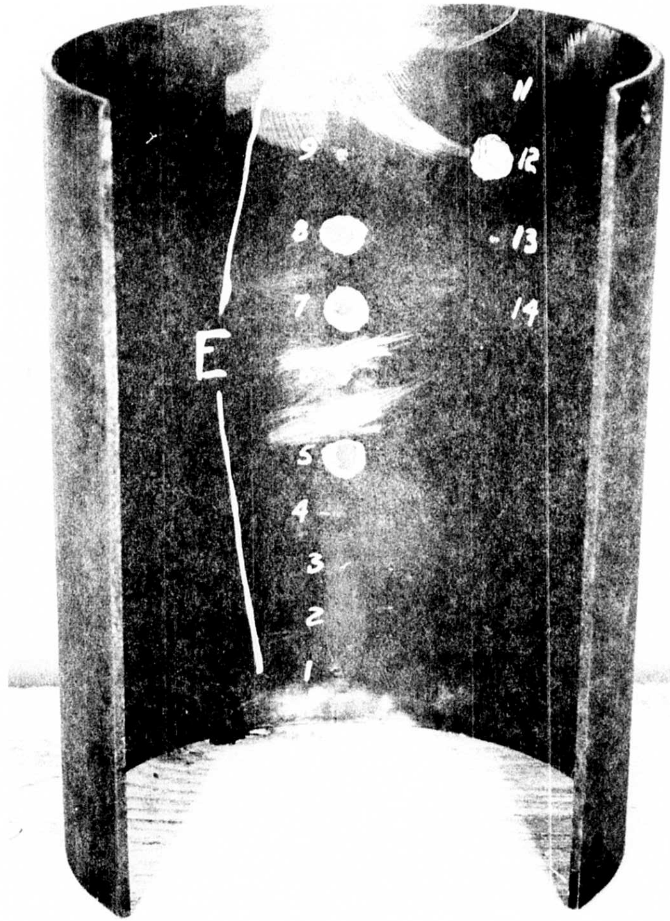


Figure 21. (U) Rear, Test Specimen E.

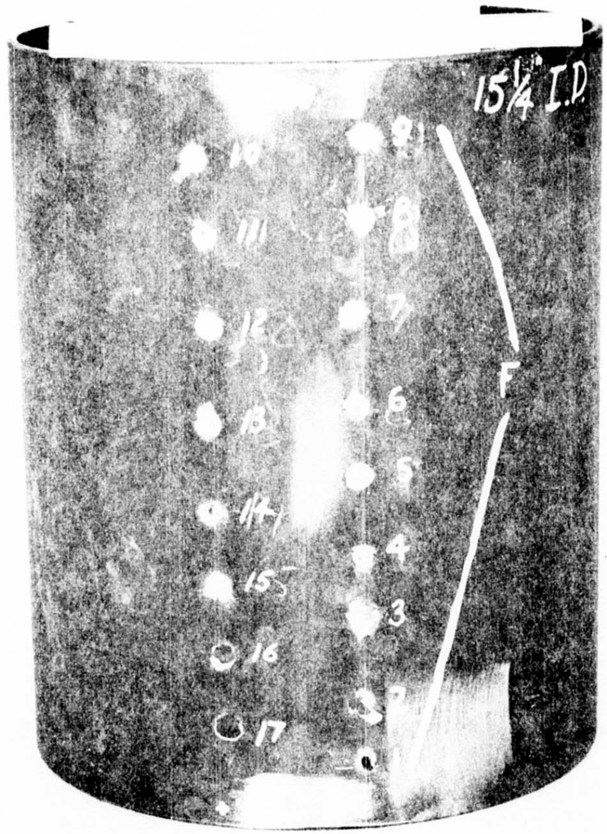


Figure 22. (U) Front, Test Specimen F.

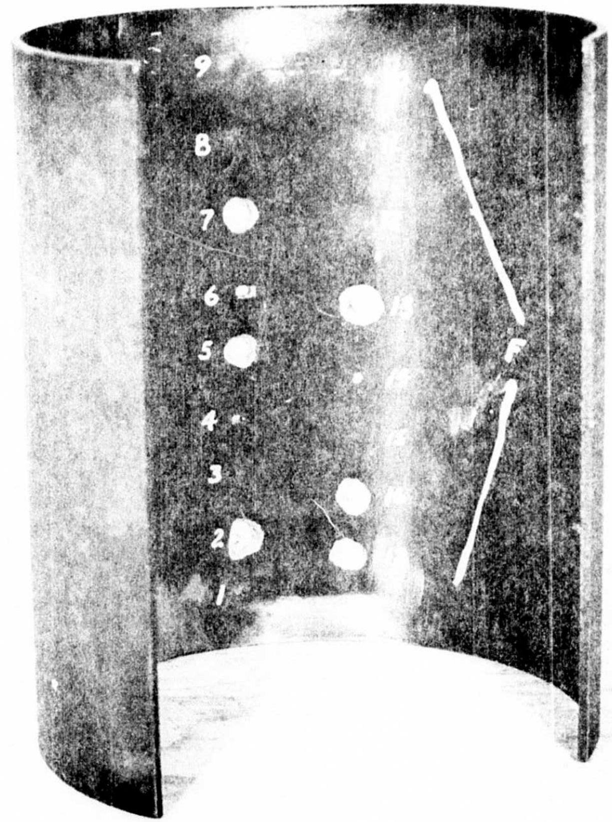


Figure 23. (U) Rear, Test Specimen F.

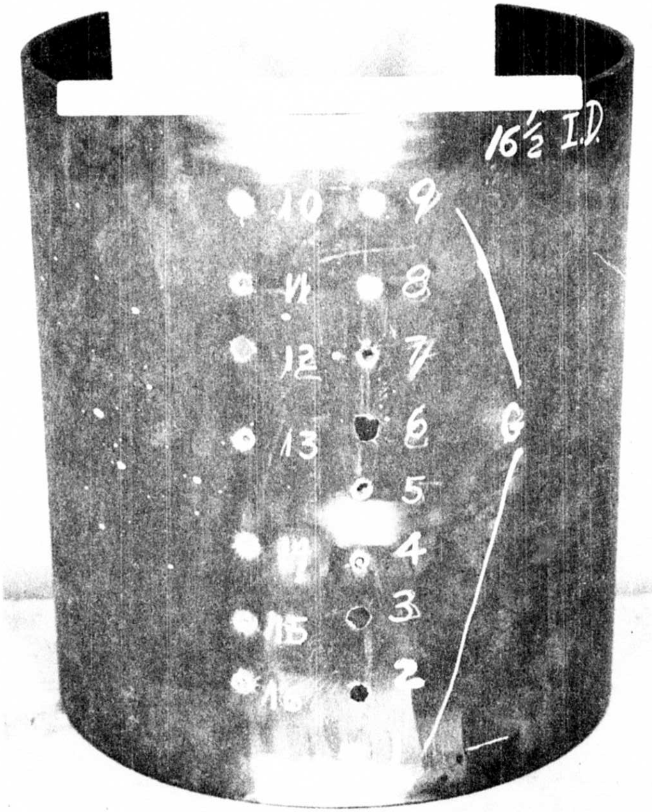


Figure 24. (U) Front, Test Specimen G.

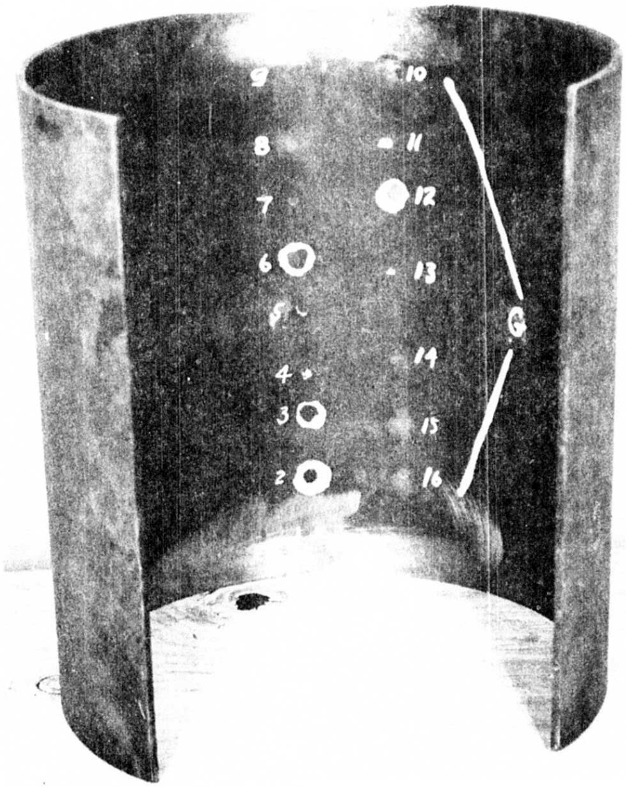


Figure 25. (U) Rear, Test Specimen G.

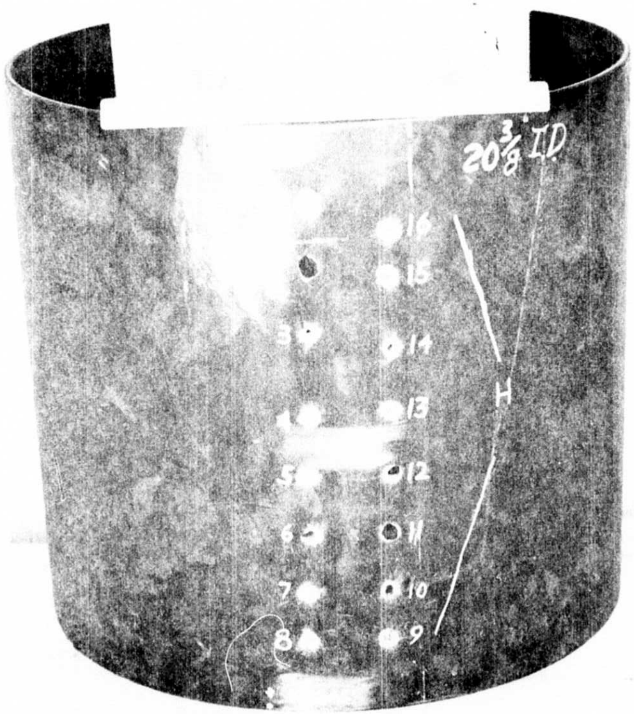


Figure 26. (U) Front, Test Specimen H.

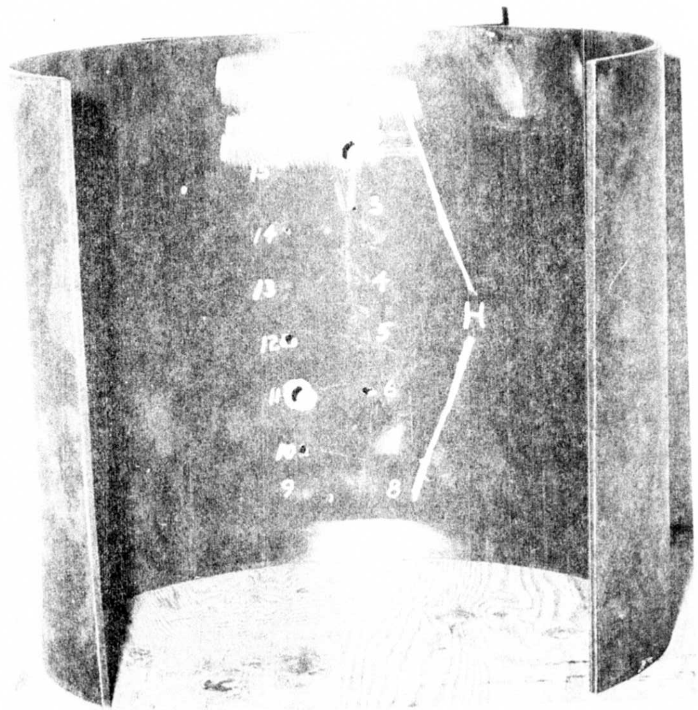


Figure 27. (U) Rear, Test Specimen H.

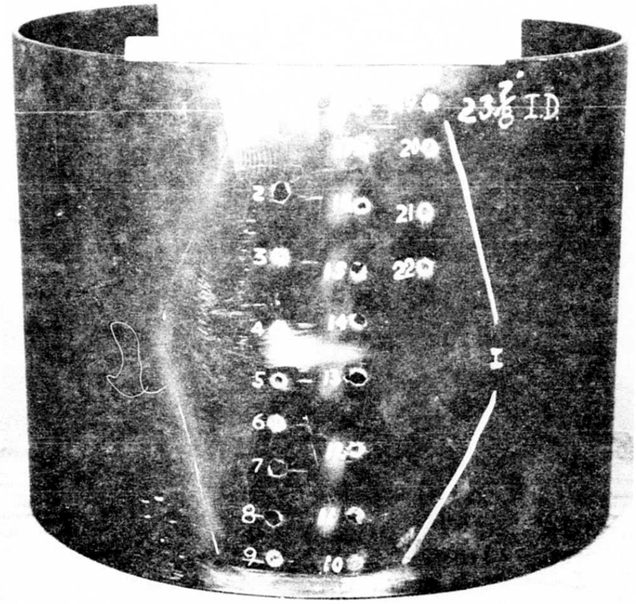


Figure 28. (U) Front, Test Specimen I.

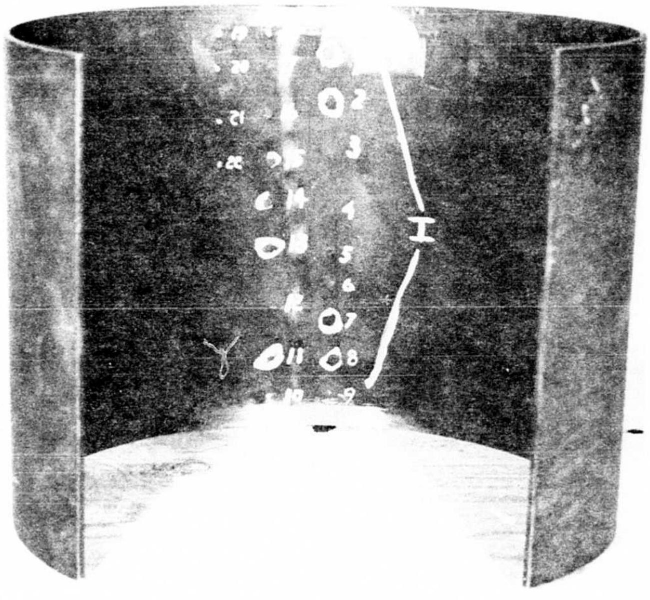


Figure 29. (U) Rear, Test Specimen I.

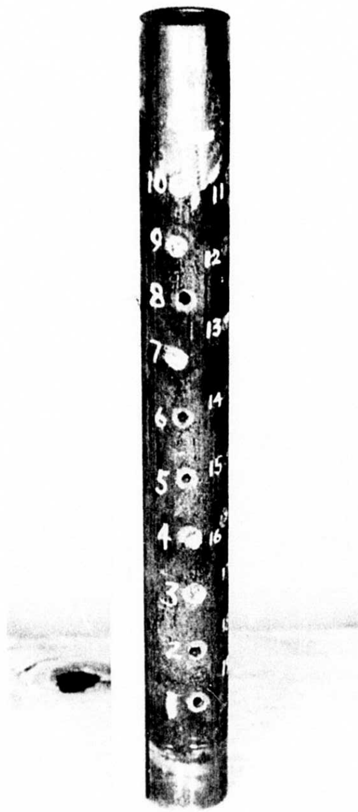


Figure 30. (U) Front, Test Specimen L.

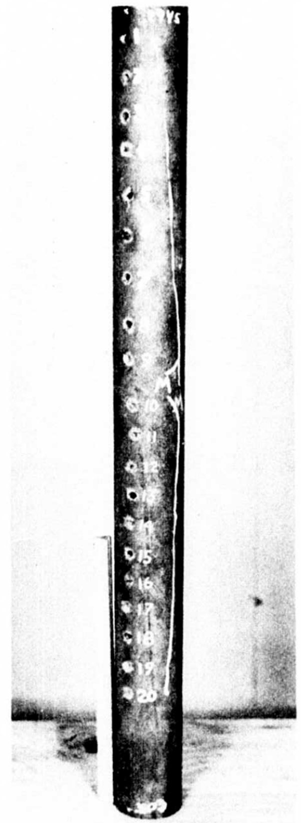


Figure 31. (U) Front, Test Specimen M.

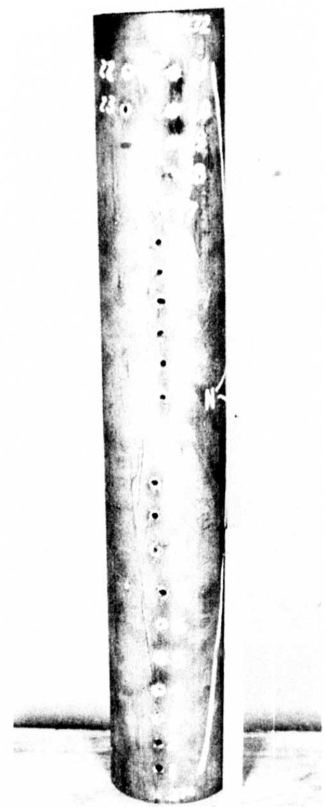


Figure 32. (U) Front, Test Specimen N.

(U) CONCLUSIONS

It is concluded that:

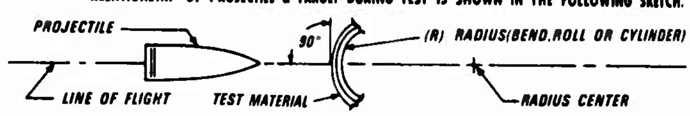
1. Formed DPSA, such as the bent and rolled sections tested in this program, performs approximately equal to flat-plate DPSA when ballistically impacted.

2. DPSA cylinders formed by the coextrusion process are only slightly less effective than flat-plate DPSA when ballistically impacted. However, they do not form large back spall fragments.

(C) APPENDIX

BALLISTIC TEST DATA SHEETS (U)

CONSTANTS DURING TEST: CAL.30 AP M2 PROJECTILES, YAW ANGLE 0°, TEST MATERIAL DPSA, RELATIONSHIP OF PROJECTILE & TARGET DURING TEST IS SHOWN IN THE FOLLOWING SKETCH.



TEST NO.	TEST MATERIAL THICKNESS (in.)	HARDNESS (Rc) FRONT	HARDNESS (Rc) REAR	(R)RADIUS (in.)	VELOCITY (ft/sec)	COMMENTS
A-1	.288	61	51	3/8	2663	CP, LBSP
A-2					2670	PP, NFI
A-3					2667	PP
A-4					2694	CP, NFI, LBSP
B-1	.287	61	52	1/2	2712	CP, LBSP
B-2					2683	CP, LBSP
B-3					2601	CP, NFI, LBSP
B-4					2574	PP, NFI
B-5					2604	CP, NFI, LBSP
B^{11}-6	.287	59	50	5/8	2632	CP, NFI, LBSP
B^{11}-7					2471*	CP, LBSP
B^{11}-8					2358*	PP
B^{11}-9					2398	PP, NFI
B^{11}-10					2421*	CP
B^{11}-11					2414*	CP
B^{11}-12					2378	PP, NFI
B^{11}-13					2424*	PP
B^{11}-14					2414*	PP
B^{1}-1	.287	59	50	Flat Section	2508*	PP
B^{1}-2					2500*	PP
B^{1}-3					2534*	CP
B^{1}-4					2554*	CP, LBSP
B^{1}-5					2484*	PP
B^{1}-6					2513*	CP
B^{1}-7					2454	PP
B^{1}-8					2465	PP
B^{1}-9					2472	PP
B^{1}-10					2449	PP
B^{1}-11					2426	PP
C-1	.288	61	51	7/8	2370	PP, NFI
C-2					2470	PP, NFI
C-3					2545	PP
C-4					2550	PP
C-5					2626	PP
C-6	.289	61	51	7/8	2626	PP, NFI
C-7					2625	PP, NFI
C-8					2789	CP, LBSP
C-9					2692	PP, NFI
C^{1}-1	.288	61	51	7/8	2686*	CP, LBSP
C^{1}-2					2592*	PP
C^{1}-3					2621*	CP
C^{1}-4					2597*	PP
C^{1}-5					2637*	PP
C^{1}-6					2637*	CP, LBSP
A^{1}-1	.288	61	51	Flat Section	2654*	CP, LBSP
A^{1}-2					2625*	PP
A^{1}-3					2637*	PP
A^{1}-4					2622*	PP
A^{1}-5					2622*	CP, LBSP
A^{1}-6					2652*	CP, LBSP

*Used to calculate ballistic limit

PP - Partial penetration
CP - Complete penetration
NFI - Not a fair impact
LBSP - Large back spall plug

TEST NO.	TEST MATERIAL THICKNESS (in.)	HARDNESS (Rc) FRONT	HARDNESS (Rc) REAR	(R)RADIUS (in.)	VELOCITY (ft/sec)	COMMENTS
E-1	.286	60	52	6-3/4	2618*	CP
E-2					2645*	PP
E-3					2558	PP
E-4					2626	PP
E-5					2665	CP, LBSP
E-6					2642	PP
E-7					2708	CP, LBSP
E-8					2668	CP, LBSP
E-9					2658	CP
E-10					2680	PP
E-11					2672*	PP
E-12					2621*	CP, LBSP
E-13					2651*	PP
E-14					2642*	CP
F-1	.287	61	53	7-5/8	2690*	CP
F-2					2663	PP
F-3					2630*	PP
F-4					2660	CP
F-5					2644	CP, LBSP
F-6					2618*	CP
F-7					2600*	CP, LBSP
F-8					2577	PP
F-9					2584	PP
F-10					2608	PP
F-11					2572	PP
F-12					2626	PP
F-13					2638	CP
F-14					2577*	CP
F-15					2638*	PP
F-16					-	CP, LBSP
F-17					2668	CP, LBSP
G-1	.284	60	51	8-1/4	2679*	PP
G-2					2654	CP, LBSP
G-3					2660	CP, LBSP
G-4					2642	CP
G-5					2679*	PP
G-6					2611	CP, LBSP
G-7					2558*	CP
G-8					2572	PP
G-9					2577	PP
G-10					2558	PP
G-11					2601	CP
G-12					2572*	CP, LBSP
G-13					2562*	CP
G-14					2587*	PP
G-15					2589*	PP
G-16					2580	PP
H-1	.287	60	51	10-3/16	2628	PP
H-2					2632	CP, LBSP
H-3					2632	CP
H-4					2580	PP
H-5					2557*	PP
H-6					2621*	CP
H-7					2637	PP
H-8					2640*	PP
H-9					2654*	PP
H-10					2637	CP
H-11					2654	CP, LBSP
H-12					2616*	CP
H-13					2541	PP
H-14					2591*	CP
H-15					2611	PP
H-16					-	PP

*Used to calculate ballistic limit

PP - Partial penetration
CP - Complete penetration
NFI - Not a fair impact
LBSP - Large back spall plug

TEST NO.	TEST MATERIAL THICKNESS (in.)	HARDNESS (Rc) FRONT	HARDNESS (Rc) REAR	(R)RADIUS (in.)	VELOCITY (ft/sec)	COMMENTS
I-1	.287	60	53	11-15/16	2602	CP
I-2					2647	CP, LBSP
I-3					2620*	PP
I-4					2630*	PP
I-5					2644	CP
I-6					2582	PP
I-7					2584	CP, LBSP
I-8					2599	CP, LBSP
I-9					2592*	PP
I-10					2566	PP
I-11					2602	CP, LBSP
I-12					2547*	CP
I-13					2609	CP, LBSP
I-14					2589	CP, LBSP
I-15					2592	CP, LBSP
I-16					2589	CP
I-17					2516	PP
I-18					2586	CP
I-19					2601	CP
I-20					2592	CP
I-21					2525*	CP
I-22					2533*	CP
D-1	.288	60	51	5-5/8	2658	CP, LBSP
D-2					2528	PP
D-3					2534	CP
D-4					2522	CP
D-5					2503	PP
D-6					2498*	CP, LBSP
D-7					2556	CP, LBSP
D-8					2452	PP
D-9					2532*	PP
D-10					2488*	CP
D-11					2527	CP
D-12					2562	CP, LBSP
D-13					2475*	CP
D-14					2466	PP
D-15					2443	PP
D-16					2439	PP
D-17					2531*	PP
D-18					2519	PP
D-19					2543*	PP
D-20					2558	CP
L-1	.288	59	50	3/4	2623	CP
L-2					2540	CP
L-3					-	PP
L-4					2546*	PP
L-5					2530*	CP
L-6					2559	CP
L-7					2486	PP
L-8					2511*	CP
L-9					2618*	PP
L-10					2549*	PP
L-11					2501	PP
L-12					2519	PP
L-13					2547	CP
L-14					2540	PP
L-15					2527	PP

*Used to calculate ballistic limit

PP - Partial penetration
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4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

Final Report

5. AUTHOR(S) *(First name, middle initial, last name)*

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13. ABSTRACT

This report contains the results of ballistic testing of fabricated sections of Dual-Property Steel Armor (DPSA). Specific items considered were bent, rolled, and extruded sections that simulated the geometry of close-fitting armor for critical aircraft components. Ballistic data for flat-plate sections were available prior to this program; however, the data did not include the geometric or fabrication effects. The purpose of this program was to determine whether the ballistics armor characteristics changed as a result of fabrication. Within the range of the formed sections tested, no significant changes were noted in the ballistic properties of the material as a result of the forming operations. (U)

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Dual-Property Steel Armor (DPSA) Dual-Hardness Armor Vulnerability Reduction Heat-Treatable Dual-Property Steel Armor Ballistic Limit						